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## Layout optimization of a repair facility using discrete event simulation

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### Abstract

Technological advancements in the field of simulation have enabled production managers to model and simulate their facilities under various scenarios, in order to optimize system performance. In particular the reconfiguration of factory layouts can be time consuming and expensive; Discrete Event Simulation (DES) can be used to model and assess various scenarios to assist production managers with layout planning. Significant benefits can be achieved through the use of DES for factory layout optimization including: decreased lead times, reduced manufacturing costs, efficient materials handling and increased profit. This paper presents the development of a DES model in WITNESS for the analysis and factory layout optimization of a repair facility. The aim of the model is to allow decision makers to assess various layouts and configurations with a view to optimize production. The model has been built with a link to an Excel spreadsheet to enable data input and the visualization of Key Performance Indicators (KPIs). Specific functions have been built into the simulation model to set and save new layouts within Excel to facilitate layout optimization. The model will be used to optimize the factory configuration.

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*Keywords:* discrete event simulation; factory layout optimization

### 1. Introduction

Effective factory layout planning is imperative to the survival of manufacturers in a globally competitive environment [1], particularly as manufacturers are required to be increasingly agile in order to keep up with varying customer demand and product mix [2]. Well-designed facilities result in efficient materials handling, reduced resource transportation times and decreased production cycle times [3]. In addition, effective layouts can reduce manufacturing costs and improve operational performance [4].

The reconfiguration of manufacturing and repair facilities can be a disruptive, expensive and time consuming process. This leads to the requirement for modelling of the system to assist managers to understand the effects of changes on their

manufacturing systems [5]. Manufacturing facilities are often too complex to be modelled mathematically; this gives rise to the need for Discrete Event Simulation (DES) methods. DES can be used to assist managers in modelling and simulating the performance of their manufacturing systems [6].

In recent years the use of DES has greatly increased, this can partly be attributed to increased competition and tool availability [7]. Various simulation trends have been identified by authors, such as the shift in the application of DES from design to operations [4]; this enables the benefits of simulation to be realized further downstream in manufacturing processes. A key trend noted by authors [4], [7], is the increased use of hybrid modelling methods and optimization algorithms; these new links greatly increase the capability of DES and provide further benefits for manufacturers.

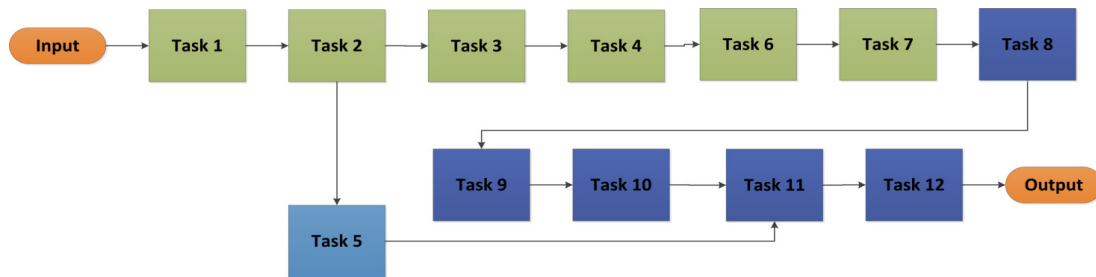


Figure 1- A flow chart to show the repair process

This paper presents the development of a 2D DES model in WITNESS for the factory layout optimization of a repair facility. In particular, the factory production managers are required to reconfigure the facility for the next repair cycle. The managers require the ability to model, test and analyze new configurations in order to de-risk the implementation phase.

This paper extends previous work in the field of DES through the development of functions to assist in layout planning. This project uses model spatial awareness, the capability in the simulation model to obtain and set the positions of different machinery in order to assess various layouts with respect to the distance travelled by parts. An Excel based interface has been developed to allow users to input variables and their desired layouts, the corresponding layout and configuration is then automatically created within the simulation model. This functionality will enable production managers to leverage their knowledge of the process to design an optimized future factory layout.

The paper is organized as follows: section 2 describes the problem, section 3 presents the features of the developed simulation model, section 4 outlines the Excel spreadsheet link, section 5 presents the results and discussion and the conclusions and future work are discussed thereafter.

## 2. Problem description

A repair facility carries out the periodic repair of parts. The repair facility requires reconfiguration to align with changes for every major repair cycle.

Factory managers would benefit from the ability to test various layout configurations and to assess them with respect to key performance indicators. In particular the distance travelled by the parts can be used as an indicator to identify optimal configurations, as materials handling processes can account for 12-50% of manufacturing costs [8]. Additionally the utilization of each workstation and of the workers is of interest to management, as this information will enable reconfiguration to reduce bottlenecks and to eliminate waste from the repair process. The following subsections describe the overall process; these key features are required to be captured in the simulation model.

### 2.1. Overhaul process description

The flowchart in Figure 1 shows the repair process for each part for a specific studied repair program. The part is

disassembled into 3 main sub-assemblies during the repair process. The sub-assemblies are then re-assembled, tested and shipped in batches.

Each part has an associated type. The parts must arrive and leave the facility in two different set sequences based on their part types. Hence, during the repair process, the sequence of part types is changed. This change of sequence has been indicated in Figure 1 by the colors of the repair tasks. The green tasks represent the parts moving along in the input sequence, the blue tasks show the parts moving through the process in the output sequence. The task in purple is a sub assembly repair task.

Although the sequence is set, the factory managers and staff often use their own knowledge of the priorities of the parts to override the sequence. Managers and workers use their initiative to put through the parts which have a higher priority due to being required early in the output sequence.

There are 12 main workstations within the facility; Table 1 shows the workstations, cycle times (normalized and scaled between 0 and 100) and number of workers at each workstation. Task 5 is split into two identical workstations carrying out the same task. Task 7 can be carried out at one of 4 identical stations; the 1 worker is shared amongst all 4 workstations. Task 7 has 4 different cycles, two of which can be automated. Tasks 3 and 10 share 1 worker; this is due to the smaller cycle times of these tasks.

### 2.2. Repair facility layout

The facility is rectangular in shape and has a wall down the center. There are 4 cranes within the factory, 2 on either side of the wall. Effectively each crane services one quadrant of the factory although having two on each side also provides more flexibility and cover during breakdowns. There are 4 gaps in the wall which are used to move parts between the two sides of the facility. The movement of parts between the two sides of the factory is more complex as this may require cranes from both sides and other equipment such as trolleys.

## 3. Simulation model development

DES was identified as the ideal method to use for modelling and optimization of the repair factory layout. A 2D DES model was built using WITNESS simulation software to enable factory managers to assess various configurations of the factory. The following subsections detail the main aspects of the simulation model.

Table 1- a table to show the cycle times, number of stations and workers for each process. \* indicates the worker is shared amongst workstations.

Tasks	Number of stations	Cycle times (scaled)	Number of workers
Task 1	1	12	1
Task 2	1	12	1
Task 3	1	12	1*
Task 4	1	38	3
Task 5	2	90	6
Task 6	1	39	2
Task 7 cycle 1	4	0	1
cycle 2		100	
cycle 3		0	
cycle 4		71	
Task 8	1	38	1
Task 9	1	38	3
Task 10	1	12	1*
Task 11	1	38	2
Task 12	1	46	1

### 3.1. Workstations, buffers and parts

Within the simulation model 12 machines were created to represent all of the workstations within the overhaul process. The workstations can be selected and moved easily to change the layout of the facility. The workstations were modelled as single cycle machines with the exception of the Task 7. The 4 workstations each were modelled as multi cycle machines, with 4 cycles for the manual and automated processes. Task 5 was modelled as two workstations which carry out identical tasks. All of the machines were modelled to require workers to carry out the tasks.

Various buffers were created within the simulation model to model areas within the factory which are used to store parts. The buffers which have been created are as follows:

- Before workstation 1
- After workstation 7
- Before workstation 9
- After workstation 9
- Before workstation 5
- After workstation 5
- After workstation 11
- Before shipping

Three main sub-parts are used within the simulation model. The parts arrive in the model in batches. They are put into the first buffer on arrival. During the 12 main tasks the parts are disassembled, maintained, reassembled, tested and shipped.

### 3.2. Part types

The parts arrive and leave the factory in different sequences according to the part types. Within the simulation model, 2 arrays have been created to represent the input and output sequences.

Within the factory the managers and workers use their knowledge of the overhaul process and the input and output

sequences to change and adjust the sequence as it seems fit. Often the workers will prioritize certain parts and ensure the chosen parts complete the overhaul process before others; this is required in particular for parts which appear early in the output sequence. This intuition of workers and managers is difficult to build into the model. In order to model these sequence changes, the input and output sequences have been built into the Excel spreadsheet as user inputs; this enables users to input their priorities into the simulation model. This allows the model to more accurately reflect the reality of the factory. The sequence change has been built into the simulation model using a built in 'match' rule within WITNESS, Task 8 will only pull in parts in the correct output sequence as defined by the user.

### 3.3. Path movement

There are a number of paths within the factory which are used by the workers. The movement of parts from one side of the wall to the other must also be carried out on one of 4 paths. Other crane based movements can occur in any direction and they do not require a path.

A key requirement of the simulation model is full flexibility to move any of the workstations to any location in order to test various configurations. The modelling of the movements between workstations is therefore modelled flexibly using a construct in WITNESS called a pseudo path. These show movement "as the crow flies" between locations and the distance can be incorporated into journey timings. When good or optimal solutions are found fixed paths for movement can be detailed as needed, with full path constructs replacing the pseudo paths, for any particular design requiring more detailed assessment.

### 3.4. Materials handling equipment

During the repair process various materials handling equipment is used to move the parts around the facility. There are 4 cranes within the facility and in the model one is assigned to each quadrant of the factory. There are also 4 different trolleys which are used to push parts around manually. The model must enable the attaching and detaching of different material handling equipment.

The material handling equipment has been modelled as variables within the WITNESS model as a simple approach that allows for a great deal of flexibility to attach and detach equipment at any stage in the process. Each of the 4 cranes has been modelled as a separate indicator variable (taking the value of 1 or 0). The trolleys have been modelled as a pool of 4 trolleys which can be accessed. In order to calculate which material handling equipment is required, the model must first check in which quadrant a particular movement begins and in which quadrant the movement ends; this calculation is carried out in Excel and is explained in section 4.

Figure 2 shows the location of the 4 quadrants within the facility, each of which is served by 1 crane. Quadrants 1 and 2 are on one side of the wall and quadrants 3 and 4 are on the other side.

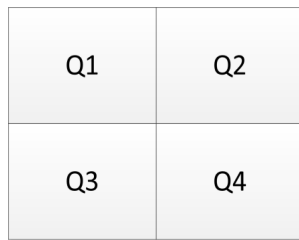


Figure 2- A diagram to show the location of the 4 quadrants within the factory

In order to check the availability of the required materials handling equipment an ‘AcceptMove’ function was created; this function is executed when a part is input into any machine. This function uses the task number of the process to assess which movement is required. The Excel spreadsheet is then used to assess which corresponding material handling equipment is required. Then the function ‘AcceptMove’ is used to check the availability of the required equipment; if the equipment is available, the corresponding variable will be decremented and the move will be carried out, otherwise the part will wait.

A corresponding ‘FinishMove’ function was also created to increment the materials handling variables after each movement has been completed within the simulation model.

### 3.5. Movement times

The simulation model is required to accurately model the time taken for the movements within the factory. The movement between different locations uses a variety of materials handling resources. For instance parts which move from one side of the wall to the other often require two cranes, one from each quadrant, and a trolley to move the part. With the complexity of different materials handling equipment the time taken for the movement is often complex to calculate and can be lengthy. Typically the time taken for movements will vary from 0-8 minutes, more complex movements may take longer.

As the model has been created to allow all of the workstations to change location, the equipment requirements will also change whenever the layout is changed. This leads to new movement times for any new layout configurations. Due to timing complexities it was decided not to simply base timings based on direct distances between locations. Instead a fully flexible array has been created in Excel to allow users to input estimated movement times for each movement. This input array will enable users to configure the model to create realistic representations of the factory, rather than relying on a distance factor which does not account for movement complexity.

### 3.6. Workers and shift patterns

A pool of workers has been modelled to represent the main labour pool within the factory. Task 7 work areas are attended by 1 specific worker; so a separate worker has been modelled for this. One worker is shared between task 3 and 10; so one

worker has been modelled just for these two workstations. All workers are modelled to work on a set shift pattern. In the initial model setup an 8 hour shift pattern has been set for each of 5 days a week.

## 4. Excel spreadsheet link

The simulation model has specifically been built for users who are not familiar with DES or WITNESS. In order to enable easy access to data within the model, a link was created between the simulation model and an Excel spreadsheet. The spreadsheet acts as a more user friendly interface for users. The following subsections detail the various features of the spreadsheet which have been added to assist factory managers with decision making; this includes the important functionality to test different factory layouts.

### 4.1. Input and output data

The Excel spreadsheet has been created to enable users to input key information into the simulation model, and to visualize the outputs in order to assess the performance of the simulation model.

Input data	Output data
Cycle times of workstations	Current position of each workstation
Movement times	Distance travelled by parts
Shift patterns and overtime	KPIs: <ul style="list-style-type: none"> <li>• Weeks completed</li> <li>• Parts shipped</li> <li>• Number of parts in final buffer</li> <li>• WIP</li> <li>• Utilization statistics for all workstations</li> <li>• Utilization statistics for workers</li> <li>• KPIs for when workers are on shift</li> </ul>
Input sequence of types	Utilization graphs of workstations
Output sequence of types	Utilization graphs of labour
New position of each workstation	

Figure 3- A table to show the input and output data within the Excel spreadsheet

Data which is input into the spreadsheet will be brought into the simulation model when the model initializes. The output data and key performance indicators (KPIs) are printed after every simulated week. The output data is specifically used to assess whether the model reflects the real production rate, i.e. one batch a week. Figure 3 is a table which lists all of the data which is input and output data from the spreadsheet.

### 4.2. Factory layout optimization

The key use of the simulation model is to test various layouts and configurations of the factory with the view to optimize the factory layout. In order to enable testing of

layouts, 2 worksheets were created within the Excel spreadsheet to record the coordinate locations of workstations in the simulation model and to test new locations; they are explained in the following subsections.

#### 4.2.1. Get position function

A 'GetPosition' worksheet has been created which is used to print the coordinate locations of all of the elements in the simulation model. The built in WITNESS functions 'GetXPosn' and 'GetYPosn' were used to print the X and Y coordinates of the location of each workstation. A new toolbar has been created in the model with a 'GetPosition' button. Users can rearrange the workstations within the simulation model, and then click the 'GetPosition' button and see the new coordinates in the Excel spreadsheet.

The X and Y coordinates of each location have then been used to estimate the distance travelled by parts during the overhaul process. For each of the main movements within the factory the direct distance is calculated between workstations. Pythagoras' theorem is used to calculate the direct distance between workstations. The sum of all of the individual distances is then used to estimate the total distance travelled. The total distance travelled is a main KPI which will be used by managers to assess factory layouts, as this effectively minimizes material handling.

#### 4.2.2. Set position function

A 'SetPosition' worksheet has also been created to allow users to set the model to any chosen layout. The built in 'SetPosn' function within WITNESS has been used to select the X and Y coordinates within the worksheet and to use them to set the factory layout to the new configuration. A button has been added on the model toolbar named 'SetPosition' which will take the values from Excel and change the layout according to those values. This functionality is particularly useful as users can test many configurations and then revert back to a baseline. The 'GetPosition' and 'SetPosition' functionality is intended to be used to enable the users to perform manual optimization of the factory layout. There are a finite number of potential layouts and there are many physical constraints governing realistic layouts. This functionality will allow users to leverage their knowledge of the facility to perform quick testing of realistic layouts, to optimize the final layout.

#### 4.3. Materials handling equipment requirements

In order to assess which materials handling equipment is required for each movement, the coordinates of the workstations within Excel have been leveraged. There are 15 major movements within the factory.

The start and end quadrant of the movement will govern which materials handling equipment is required. There are 10 different combinations of requirements which could occur based on the starting and finishing locations of parts. The numbers 1-10 are used to index which equipment is required. The index of materials handling equipment requirements is as follows:

1. Only Q1 crane is required
2. Only Q2 crane is required
3. Only Q3 crane is required
4. Q4 crane and 1 trolley are required
5. Q1 and Q2 cranes are required
6. Q3 and Q1 cranes are 1 trolley required
7. Q1, Q3, and Q4 cranes and 1 trolley are required
8. Q3, Q1 and Q2 cranes and 1 trolley are required
9. Q2 and Q4 cranes and 1 trolley are required
10. Q4 and Q3 cranes are required

A look up matrix has been created in Excel which shows the start quadrant as rows and the end quadrant as columns. An index function has been written in Excel to check the start and finish quadrant of each of the 15 movements and to return the corresponding number of the movement requirement.

The result is a 15x1 array. Figure 4 shows the look up matrix, the values within the matrix relate to the index above.

	Q1	Q2	Q3	Q4
Q1	1	5	6	7
Q2	5	2	8	9
Q3	6	8	3	10
Q4	7	9	10	4

Figure 4- A look up matrix to show the different possible factory movements. Values relate to the list above.

An array named MovementRequirement has been created within the simulation model which extracts the values from the Excel array for each of the 15 main movements. Within the simulation model each time a movement is required the corresponding MovementRequirement number is passed into the 'AcceptMove' function and the function checks if the matching materials handling equipment is available. If the equipment is available the equipment variable is decremented and the move is carried out, otherwise the part will wait.

## 5. Results and discussion

Initial testing of the model was carried out to assess and validate the model. The KPIs in particular were used to assess if the model adequately represents the factory production rate. Four different scenarios were tested to compare the model results with different inputs. All scenarios were run for 25 simulated weeks to assess the distances travelled, number of batches shipped and production rates.

The first scenario tested was the current production scenario within the factory. Cycle times and movement times were added into the Excel spreadsheet.

The model results showed the distance travelled by major parts as 212 meters. The utilization of the workstations is shown in the top bar chart in Figure 5. The model completed 22 batches within 25 weeks, with the work in progress (WIP) rising to 85 within the final simulation week; this value represents an additional batch waiting for overhaul. The results showed that with the first cut input data the model did not match the factory production rate of 1 batch a week (with an exception of the ramp up period in the first week).

A second scenario was tested with an identical configuration to the first model, but with a 10% reduction in

the cycle times of all workstations. This was carried out to attempt to match the production rate of the factory. The results showed the factory completed 24 batches within the 25 week time period. The production rate was stable with 1 batch produced per week with static WIP over the 25 weeks.

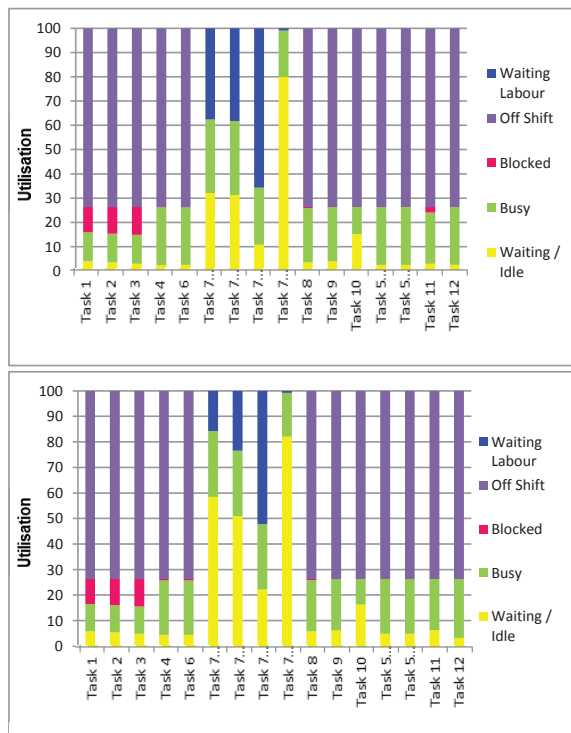


Figure 5- Utilization graphs of the first scenario (above) and second scenario with cycle times reduced by 10% (below)

The utilization is also shown in the lower bar chart in Figure 5. The waiting/idle time of stations has increased; this is particularly clear for the 4 workstations for Task 7. In addition the final assembly stage is no longer blocked.

A third and fourth scenario were also tested to assess the effect of changing the location of 2 workstations. Two of the workstations have been moved to a different part of the factory. The new distance travelled by parts for scenario 3 and 4 is 302 meters.

The third scenario used the identical inputs to the first scenario, with original cycle times. The movement times were updated to account for the complexity of the new movements. Results produced were identical to the results from the first scenario, with identical utilization of all machines, as shown in the upper bar chart in Figure 5, and production rate of 22 batches in the 25 week period. The fourth scenario used identical inputs to the third scenario with 10% reduction in cycle times. Results produced were identical to the results from the second scenario, with identical utilization of all machines, as shown in lower bar chart in Figure 5, and production rate of 24 batches for the 25 week period.

Results suggest that the model production rate is somewhat insensitive to both movement times and to the factory layout with current data inputs. However the model is sensitive to

changes in cycle times, as would be expected given the long duration of some tasks. The improved match to observed data in model scenario 2 indicates that the production rates may be greater than initially entered into the model. Further data collection of cycle and movement times is required to confirm this. Preliminary feedback includes a requirement from factory management to visualize the individual utilization of the workers within the workstations; the model will be updated to include this modification.

## 6. Conclusions and Future work

To conclude a DES model has been created of a repair facility in WITNESS; the model enables factory managers to test various layouts and configurations in order to optimize production. Various features have been built into the simulation model and the Excel spreadsheet to allow users to carry out configuration testing and to identify optimal solutions. These features include functions to automate layout planning, in order to facilitate layout optimization.

Further analysis is required to assess and confirm the influence of the cycle and movement times on the overall production rate; data collection is required to verify that the provided cycle times are accurate. In the next stages a 3D model will be built with fixed paths for an optimized layout. This virtual prototyping will assist with early error detection to reduce problems in the implementation phase of the new layout.

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